DISCUSSION BEFORE THE INSTITUTION, 11TH APRIL, 1935.

Colonel A. S. Angwin: There are two aspects of the paper which are of very great interest to this Institution. First, the paper gives a general picture of the latest and the most powerful station of the B.B.C. Secondly, it gives particulars of some very notable advances in the technique of broadcasting.

The summary which the authors give of the factors influencing the choice of the station is based on the assumption that the polar diagram in the horizontal plane is approximately circular. Means have, however, been suggested and adopted elsewhere for obtaining a polar diagram which is not truly circular but may be of an oblong shape. What is the authors' opinion with regard to the possibility of using one or more partial reflectors with the object of spreading the polar diagram and thus getting a better signal strength in the more remote parts of Scotland, where there seems to be great difficulty in getting an adequate field strength? It would also be of interest to have the authors' idea as to what in fact the polar diagram is in the vertical plane for the long-wave aerial. I assume that with this type of aerial—with a comparatively low capacitance at the top—the major part of the radiation is projected at fairly low angles with the horizontal. There must still, however, be a fair amount of radiation at an appreciable angle with the horizontal, and this radiation is ineffective so far as a national service is concerned. It reaches the Heaviside layer, is reflected down, and may give a very adequate broadcasting service in other countries. An aerial of this sort is inefficient for the purpose of providing the required field strength at such points as the extreme north of Scotland.

Turning to the question of the series modulation system, I assume that this system was adopted in order to achieve the best possible frequency characteristic with the minimum of distortion; that objective has been achieved. Of the factors concerned in the choice of that system, one, namely economy, has not perhaps been given full prominence. The amount of heat which is necessarily dissipated in the final stage is very much higher in the case of series modulation than with high-power modulation. Dealing with a carrier energy of the order of 150 kW, the heat dissipated in the final stage with the system in use at Droitwich is something of the order of 335 kW under carrier conditions, whereas with high-power modulation the corresponding figure would be of the order of 100 kW. Taking normal conditions of operating, this means a saving in favour of high-frequency modulation of about £3 700 per annum, assuming the cost of energy to be about 1d. per unit. £3 700 per annum is possibly a small figure compared with other considerations, but that figure when capitalized might well overcome the difficulty of getting an adequate transformer for high-frequency modulation.

I am interested in the very bold step taken by the authors in installing such high-power mercury-arc rectifiers. It is perhaps rather early to tempt them to give us any further information as to how these rectifiers are behaving in practice. I think there can be no doubt that they are advantageous from the point of view of economics; and whether they have yet got past their troubles with regard to the possibilities of breakdown will be of great interest.

I suggest that the effective height of the aerial given in the paper is a little high. Taking the authors' figure of 20·4 ohms for the resistance of the aerial plus the tuning inductances (which might give an aerial resistance of the order of 20 ohms) and their figure of 167 m for the effective height of the aerial, the calculated overall efficiency would appear to be slightly over 100 per cent.

Mr. W. T. Ditcham: In my opinion the most original feature of the Droitwich station is the matching network or "transducer." This is the first instance where such an elaborate network has been applied to a transmitter, and the comparative curves (Figs. 28 and 42) show how effectively the device has dealt with the inherent difficulty in long-wave radio-telephone transmitters of obtaining a sufficiently wide frequency response together with equal amplitude of the upper and lower side-bands. The measurements of the amplitudes of radio-frequency harmonics indicate that these are attenuated to reasonable values, although, comparing these results with measurements made on other transmitters, it is not obvious that the transducer in this respect is more effective than the usual tuned tank circuit between feeder and aerial.

Another feature of interest in the installation is the design of the 20-kV direct-current motor-generator combination, which, in conjunction with the overload short-circuiting device described in the paper, provides a very reliable and safe source of supply for high-voltage valve transmitters.

The 20-kV mercury-arc rectifiers are also interesting, and possess the desirable feature of a very high efficiency. Marconi's Wireless Telegraph Co. have been using rectifiers of this type in high-power transmitters for some time past with considerable success, but I am nevertheless in agreement with the authors' opinion (page 210) that from the point of view of reliability the d.c. motor-generator is still unrivalled.

A feature of the design which is deserving of attention is the incorporation of series modulation at a comparatively high power level. This method of modulation has proved extremely satisfactory in practice. At Droitwich this stage, delivering approximately 17 kW of carrier power at an overall efficiency of 28 per cent, can, with careful adjustments, be modulated to 90 per cent with a distortion factor of less than 2 per cent. To the best of my knowledge there is no other system of modulation with comparable efficiency which is capable of producing equal freedom from distortion, and is at the same time so convenient for high-power operation, and with the increasing demand for improved quality and reduction of interference I believe there is a considerable future for this method for broadcasting purposes.

At the time the Droitwich transmitter was planned we were not in a position to apply the series modulation method to the final stage for a power rating so high as 150 kW, as we lacked a suitable source of high potential (say, about 30 kV) and also sufficiently large modulating valves to keep the number of valves necessary to a convenient figure. Both difficulties are on the point of being removed, and we shall shortly be able to use this method of modulation for any reasonable power level.

The authors state that the harmonic content of the complete transmitter is just over 4 per cent at 90 per cent modulation, and well below 4 per cent at 80 per cent modulation. These are very creditable results, but it is obvious that the final Class B amplifier appreciably deteriorates the quality of the input supplied by the series-modulated stage. This increased distortion is almost entirely due to the disturbing effects of grid current during the upward swing of the modulation cycle, an inherent disadvantage of this method of amplification. As regards distortion, variation of anode potential is far superior to variation of grid potential when the necessary grid swing involves grid current flow. If the grid swing is confined to negative values throughout, very good results are obtainable, but with the high-power valves available at present the efficiency then becomes too low for practical consideration. We are always confronted with the conflicting requirements of low distortion and high efficiency. The B.B.C. have always regarded quality as a far more important factor than efficiency, but with the present tendency towards increasing powers the question of power consumption is assuming more and more importance.

On the other side of the Atlantic there is a strong movement in favour of modulating the final stage of the transmitters by transformer-coupled modulators connected in phase opposition and adjusted for Class B operation. This system certainly results in a considerable economy of power, but when it is worked so as to give the best efficiency the results seem to be even worse as regards distortion than those obtainable with the normal Class B radio-frequency amplifiers. There are possibilities with this system of aiming at a compromise between efficiency and distortion, by using low-impedance modulating valves and maintaining the grid potential negative throughout the modulation sweep.

The Marconi Co. have recently made use of a power-saving arrangement which I have named the "floating carrier" system. In this method the carrier power, and consequently the input power, are regulated to suit the instantaneous degree of modulation required, and as the mean modulation is always quite low, say about 30 per cent, the saving of power can be quite appreciable. This result is obtained very simply in a series-modulated stage by rectifying the tone input and applying the resultant d.c. potentials through a time-delay or "hang-on" circuit to the grid of the modulator, which thus conveniently serves to vary the carrier power and at the same time to modulate it. This method is in use in the 100-kW transmitter at Beromunster, Switzerland (wavelength 540 m), and appears to operate quite satisfactorily.

On page 210 it is stated that the rated carrier output of the transmitter is 200 kW; at present, however, only 150 kW is being generated. We have recently completed tests of a transmitter at Motala, Sweden, which is practically a duplicate of Droitwich, during which the four CAT14 valves in the final stage developed a carrier power of 220 kW. The distortion factor at 150 kW output and 90 per cent modulation was just under 4 per cent, and at 220 kW output about 5 per cent. At Motala the anode voltage supplied to the final stage is 20 kV, whereas at Droitwich the final stage is being operated at 18 kV, so that Motala was expected to do a little better as regards distortion for that reason. The principal difference between the Droitwich and Motala transmitters is that in the latter the insulated d.c. dynamos for heating the modulated amplifier filaments have been replaced by transformers fed from the 3-phase mains and arranged to produce a 90° phase difference between the filaments of each of the four CAT6 valves.

The hum level with this arrangement is about 54 decibels below 100 per cent modulation, which at the frequencies involved is probably just about the maximum hum permissible for high-quality broadcasting.

Mr. P. P. Eckersley: It is interesting to compare the present paper with that describing the first regional station,* because the comparison reveals the trend of development in high-power broadcasting-station design. The major differences between the two stations, at Droitwich and Brookmans Park, concern the power supply and the system of modulation. The further points of difference are mostly only introduced because of the much lower frequency of transmission employed at Droitwich than at the other station.

It is obviously an economy in both capital and running cost to use mercury-arc rectification of alternating current for the power supply, rather than d.c. machines; but, as the authors point out, mercury-arc rectifiers have been proved to be less reliable than d.c. machines. The authors have ingeniously combined the advantages of both systems, since reliability is maintained by a switching arrangement which brings in the d.c. machines should the mercury-arc system fail.

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* P. P. Eckersley and N. Ashbridge: *Journal I.E.E.*, 1930, vol. 68, p. 1149 and *Proceedings of the Wireless Section*, 1930, vol. 5, p. 193.

While every engineer feels it his duty, however rich or poor the authority which employs him, to study economy, it is important to study capital or maintenance cost in relation to other factors. The figures given in the paper make it possible to calculate approximately the running costs of the d.c. machine and of the mercury-arc rectifier in relation to the total costs of distributing the National programme. The most favourable comparison makes the mercury-arc system 10 per cent more efficient than the d.c. system. The total output load required is, for the long-wave station, of the order of 600 kW. If the station be assumed to work for 5 000 hours per annum, the total yearly consumption is 3×10^6 units. Assuming a figure of ½d. per unit, a 10 per cent increase in consumption means an extra cost, of running d.c. machines, instead of rectifiers, of £625 per annum.

It is not relevant to cite the saving in capital cost obtained by using mercury-arc rectifiers, because d.c. machines have to be supplied in any case to ensure reliability, and special switchgear is also supplied to make it possible to bring them into operation. Thus the capital costs of both systems are, to ensure reliability, approximately the same.

The cost of creating and distributing the National programme cannot be less than £500 000 per annum, and therefore the extra cost of d.c. operation, had it been adopted, with its attendant reliability and simplicity, would have been 0·125 per cent of the total cost of programme distribution. On the other hand, it is doubtless valuable that a body such as the B.B.C. should have information about the operation of mercury-arc rectifiers, and this it will obtain without detriment to service. I think, however, in view of these figures, that the relative economy factor of mercury-arc rectification may seem to have been unduly stressed in the paper.

It is probable, however, that in time it will be possible to increase the valve anode-supply potential, with a consequent gain in efficiency, and it would be interesting to have the authors' opinion of the relative merits of transvertors and mercury-arc rectifiers for voltages which may be 2, 3, or 4 times those we normally use to-day. The system of modulation adopted by the authors demands, in any case, an anode-supply potential double that used in conjunction with other systems commonly adopted in broadcasting practice.

The authors justify the use of the " series-connected modulator " system of modulation described in the paper in terms of the following factors: (1) The intervalve circuits necessary for a high-frequency amplifier used in connection with a low-power modulation system have to be, for long-wave broadcasting, of " a complicated design." (2) High-power modulation wherein the output valves are directly modulated would be clumsy and awkward. (3) Choke modulation may give " transient distortion." While agreeing that high-power modulation is for many reasons not to be recommended, I do not understand why the circuits necessary to amplify the modulated component in low-power modulation are considered to be so " complicated." I have found that, for low-power work at any rate, band-pass filter sections of the 3-element type are eminently suitable for the case where the ratio of extreme side-band frequency to carrier frequency is so large or small as to prohibit the use of one tuned circuit as the anode impedance. We have lately constructed transmitters wherein the greatest ratio of side-band frequency to fundamental frequency is slightly less than 1·5 : 1, and have used, with efficiency and stability, ordinary 3-element band-pass sections for the coupling impedance between stages of amplification.

Although the image impedance of a suitable type of such a structure varies, over the pass band of frequencies, from ∞ to R and again to ∞, the actual physical impedance, with a resistance-terminated 2-section filter, varies by only between 1·5 : 1 and 2·0 : 1. This variation of impedance is actually useful in offsetting the effects of dissipation in the inductance elements, which otherwise tend to round the shoulders of the frequency/response curve. It is, furthermore, a useful function of such filters, used in conjunction with low-power modulation systems, that they eliminate or tend to eliminate the harmonics of the fundamental frequency inevitably generated at the modulated amplifier. This elimination takes place at each successive stage of amplification. Besides, each filter tends to remove harmonics generated, due to non-linear magnification characteristics, in the high-frequency magnifying valves themselves. The filter system following the stage which is modulated at high power must be very elaborate and expensive to give the necessary harmonic attenuation.

This leads one to question the inherent superiority of the transducer compared with an impedance transforming band-pass filter of conventional design. The result of the measurements and calculation of the transducer show it to perform extremely satisfactorily, but it would be interesting to know what are the merits of the new system compared with those which are well known. An aerial containing inductances, capacitance, and resistance in series, is of the form of an arm of a 3-element band-pass filter and can be included as part of a filter when the required conditions of transmission can be obtained.

To return to the modulation system, the authors, by inference rather than directly, condemn the ordinary choke control methods by hinting that these can introduce transient distortion. Surely the experiments described in the paper and conducted by the research department of Marconi's Wireless Telegraph Co. might have had a different outcome if the offending choke had been shunted by a resistance having a value lower than the reactance of the choke to the lowest useful frequency. A choke in parallel with a resistance is, as regards the a.c. components generated by the action of the valve, a resistance which gives, over certain limits, no frequency discrimination; a choke is, as regards the d.c. supply to the valve anodes, a short-circuit to the resistance which, if it had to carry the full direct current, would waste a lot of power. In work lately conducted we have shown that ordinary choke control systems can be designed to give 100 per cent modulation without detectable amplitude or transient distortion.

It is obvious that any reasonably conceived system of modulation can be made to work and, given reasonable skill and care in the design of each, no listener could tell the difference between any of them. Comparison between the systems must concern economy, and ease and cheapness of construction, adjustment, and adaptation. In these terms also there is really very little to choose between the various types of circuits. In high-power systems the audio-frequency amplification is very great and the radio-frequency amplification small; vice versa, in low-power systems the radio-frequency amplification is large and the audio-frequency small. It would seem on the whole easier to design an amplifier having to magnify a gamut of frequencies wherein the ratio of the highest to the lowest is of the order 1·2:1 than one in which this ratio is 200:1, and therefore it would seem as if, on the whole, radio-frequency amplification is preferable to audio-frequency amplification. Another point which distinctly favours low-power modulation is that any circuit adaptations or modifications which an expanding art may demand are easily made with this system.

It was a little staggering to hear from Mr. Ditcham that distortion on deep modulations with systems similar to that used at Droitwich was as great as 4 per cent. There certainly seems room for improvement.

It is an added complication to have to work a filament-lighting machine at tens of thousands of volts above earth potential. In this connection would it not have been possible, seeing that the modulation takes place at such a high power level, to use a.c. lighting, which would have greatly cheapened and simplified the design?

Another change between the old and the new station of a much more vital nature, so far as the public is concerned, than any so far discussed, concerns the geographical position of the site chosen for its location. It is well known that mountainous and arid ground attenuates the ground wave more rapidly than lush or pastoral country. By moving the station from its old site at Daventry to Droitwich, the north-eastern corner of England and the Devon-Cornwall peninsular are shielded, more than they were from Daventry, by the Pennine and South Wales mountains respectively. These areas were difficult enough to serve from Daventry; are they not given a worse service than they would have had had the site been unchanged but the power of the station and the height of the aerial raised? Figures are given in the paper which show that Newcastle and Plymouth both receive a field which is less than that which would be created if the earth's conductivity along the line over which the waves must pass from the station to these cities were of the normal conductivity of 10^{-13} c.g.s. units. If my recollection serves me correctly, the line Newcastle–Daventry gave a less attenuation than standard, and the figures in the paper now show the field to be inferior to standard. There has lately been a period of very bad "long wave" fading. It was very unfortunate that this should have come at a period immediately following the opening of the Droitwich station, because the public and the lay Press obviously associated the new station with the poor service. The phenomenon was, however, observed to take place on all European long-wave stations, new or old, and so had nothing to do with the design of the station. The relevant point is, however, that the effect might have been less pronounced than it was in the environs of Newcastle and Plymouth if the site had not been moved. The suggestion is that they would have been better served, albeit those fading effects might have been noticed, had the ratio (Direct-ray strength)/(Indirect-ray strength) not been diminished in these already poorly-served areas, as it was by the change of site.

It must be remembered that the new Droitwich station uses a better aerial than Daventry with its 500-ft. masts could ever employ, and therefore presumably the ratio of horizontal to other radiation is better with the new than with the old station. The zone of intolerable fading should thus be farther from the new than from the old station, both assumed located at the same site but having different aerials.

Did the authors experience any difficulties because of the exposed feeder lines between the main building and the aerial-transformer houses? It is interesting to notice that station WOR in America uses buried feeders to prevent these effects.

The B.B.C. has in the past used the term "service area" to express what the authors mean by the ugly word "coverage." Might one put in a plea for the use of terms which are scientific rather than journalistic to describe scientific conceptions?

Lastly, it is perhaps redundant but nevertheless relevant to state that rural reception of British programmes has been vastly improved by the operation of the Droitwich station, which represents, whatever academic comparisons with other methods may be advanced, a profoundly interesting example of modern broadcasting transmission technique.

Mr. C. E. Strong: I think Droitwich will take a place in the technical history of broadcasting mainly on two accounts. The first is that it marks a reversion to modulation at relatively high power, and the second (as Mr. Ditcham has pointed out) is the scientific treatment of the question of side-band cut-off in the assembly comprising the antenna and the transforming and harmonic-suppressing network between the valves and the antenna. I note that modulation on the penultimate stage was adopted, and the question naturally arises: Will the future tendency be to go farther in that direction and to return to plate modulation on the final stage? The authors give two good reasons for modulating on a high-power stage. In the first place, the number of high-frequency circuits which must be treated from the point of view of side-band cut-off is reduced—an important point in a long-wave transmitter—and, secondly, there is a reduction in the number of high-frequency amplifiers handling the modulated wave and introducing a certain amount of non-linear distortion.

Neither of these points presents fundamental limitations, but, taken together with other advantages of high-power modulation, e.g. the reduction in the number of high-frequency stages by the use of high-amplification screen-grid valves, as is well exemplified at Droitwich, they seem to point towards a return to final-stage plate modulation.

Moreover, engineers have always been dissatisfied at not being able to make efficient use of a plate-modulated high-frequency amplifier having an efficiency of the order of 70 per cent in preference to a grid-modulated amplifier with an efficiency of only about 30 per cent simply because they did not know how to produce, with reasonable efficiency, the high-power voice-frequency supply necessary to feed the modulated amplifier. If it had only been necessary to modulate with a single frequency, such as could be obtained with good efficiency from an alternator, there would never have been a case for employing low-power modulation.

It appears, however, that the situation is now changing, and with the advent of vastly improved high-power speech-frequency transformers the programme can be raised to high power with good efficiency by means of Class B push-pull low-frequency amplifiers; and so under the new circumstances greatly improved overall efficiency can be realized by using a Class B push-pull low-frequency amplifier to modulate on the plate of a final high-frequency stage. Mr. Ditcham considers that the harmonic content in this case would be very high, but I think he is taking an over-pessimistic view in this respect.

The authors express the opinion, but with some reservation, that the particular type of plate modulation which they have adopted, namely series modulation, is advantageous from the point of view of quality of reproduction, particularly in regard to transient waveforms, owing to the absence of iron-cored speech-frequency chokes or transformers. There is, however, another school of thought which holds that the use of speech-frequency transformers—even at high power—is not inconsistent with the attainment of the accepted standards of broadcasting quality. The matter would appear to hinge around leakage reactance, and it should be viewed with due regard to the very low values of leakage reactance expressed as a percentage of the open-circuit primary inductance obtainable in the most modern transformers.

Turning to another point, the value of the capacitance in the high-tension smoothing circuit is smaller than one might have thought necessary on a basis of computation to ensure low harmonic content, but the results justify the value chosen. I should like, however, to ask the authors what harmonic content and phase distortion they estimate must be introduced by the impedance of the smoothing condenser at the lower audio frequencies, together with its series resistance.

Turning to the statement in the paper to the effect that the harmonic content for 90 per cent modulation is 4·3 per cent, I note that the fundamental audio frequency is not mentioned. It would be interesting to know over what band of audio frequencies this value holds good.

Mr. M. Shams-el-Deen: I should like to ask a few questions regarding the method of modulation adopted for the long-wave transmitter, known as " series modulation." Although I appreciate the careful experimental work which has been done by Marconi's Wireless Telegraph Co. on the problem of how to avert serious side-band cut-off without employing a complicated design which may require critical adjustment, I cannot understand why, if they aimed at faithful reproduction at the loud-speaker end of what is taking place in the studio, the B.B.C. did not use the " phase modulation " system installed by the Société Française Radio-Electrique at the Poste Parisien broadcasting station. Are the authors aware that the efficiency of the last circuit in that system is about 66 per cent, while that in the plant which we are now discussing is only about 32 per cent? Did the authors ever contemplate introducing this method into this country and, if not, why not? Looking at it from the engineering point of view, is it not far superior to the series modulation system in every respect?

Dr. L. E. C. Hughes: With regard to a level frequency/response characteristic for the side-frequencies in the antenna current, could not equalization be more easily effected in the low-frequency circuit, and so save the power loss in the line filter? In practice, the energy distribution among speech and music frequencies falls off very considerably in the higher parts of the transmitted band, and so no overloading may be feared when the levels of the upper frequencies are raised before modulation. I cannot see that it is very important for the output and antenna circuit to have a level frequency/response characteristic, provided the frequency/response characteristic of the whole system is level.

With regard to high percentage linear modulation, this can be readily obtained by modulating to a degree which is linear and increasing the percentage modulation by injecting the carrier in anti-phase in the output of the modulator. In this way Reeves* removed the carrier altogether.

Mr. J. A. Gracie: The authors state that the master-oscillator drive circuit was designed partly with a view to possible changes in the station frequency due to international arrangements. Perhaps they would state what alterations to the transducer system would be necessary in the event of a change of transmitted frequency. Perhaps, too, they could give some information regarding the amount of power lost in the transducer circuits.

Mr. P. G. A. H. Voigt: I notice that the published response curve stops at 6 000 cycles per sec. I should be interested to know whether there is any information available as to what happens above that frequency.

[The authors' reply to this discussion will be found on page 250.]

SOUTH MIDLAND CENTRE, AT BIRMINGHAM, 11TH MARCH, 1935.

Mr. D. R. Parsons: I should like to ask a question regarding the low-frequency characteristics of the National transmitter. Previously, the B.B.C. has used Heising or choke modulation, which tends to give a falling frequency/response characteristic to the transmitter, owing to the iron present. With series modulation, however, I presume it is quite possible to obtain a rising characteristic.

In view of the fact that receivers are far more distortionless than they used to be, would it not be desirable to raise the level of the higher audible frequencies and so obtain at the transmitting end the tone correction required by modern low-decrement high-frequency circuits? I should like to know the opinion of the B.B.C. on this point.

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* A. H. Reeves: *Journal I.E.E.*, 1933, vol. 73, p. 245 ,and *Proceedings of the Wireless Section*, 1933, vol. 8, p. 142.

Mr. R. K. Hartley: As regards the quality of tone in the transmissions from the Droitwich stations, I think it is a great improvement on that of the old Daventry station. The quality of the reception from the B.B.C. stations is the finest I have heard.

Mr. H. S. Dransfield: I should like to hear more with regard to the causes of the fading of the Droitwich long-wave transmitter, which has aroused interest in many parts of the country. I would also ask why the quality of the transmissions varies so widely.

When inspecting the station I noticed that the reading of the modulation ammeter was varying over wide limits; it would be interesting to know the factors that are taken into consideration in determining the amount of modulation at any particular time.

I note that the operator who listens in at the station exercises control, and I should like to know on what lines this control is arranged.

Mr. H. Hooper: I should like to know why a private power supply was installed at Droitwich. The station has four 470-kW sets running at about 78 per cent load, and taking into account the price of fuel oil delivered at Droitwich I should say that, assuming one spare set, i.e. three sets in more or less continuous operation, the cost would be not less than 0·5d. per unit, and probably nearer 0·52d. per unit. On the other hand I assume that the authors could have got a price per unit of 0·5d. delivered from a reliable source or multiple sources. It appears to me that the question of cost did not enter into the question of a private versus public supply.

Mr. C. F. Partridge: Was the mechanical strength of the material when subjected to high-frequency electrical stress used as a basis for the mechanical design of the mast supporting insulators? Why was it decided not to use grid control for running up the voltage on the mercury-arc rectifiers? In estimating a satisfactory field strength of 2·5 millivolts per metre, what type of receiving apparatus is assumed? With regard to the variation in frequency, how is this quantity so accurately measured? Why is it necessary to have such comparatively long lengths of water-filled tubing leading to the transmitting valves?

Mr. R. H. Rawll: The point that impressed me most on inspecting the station was the extraordinary efforts which had been made to duplicate the pieces of apparatus which experience had shown would probably be liable to fail, and the methods adopted to effect the change-over in the minimum of time. The supply engineer has to face a similar problem, but on a limited scale. There is a distinct difference, of course, between supply work and broadcast work, inasmuch as a distribution organization feeding a town or city has only a proportion of its consumers affected should the supply fail in a particular area of the network, whereas the results of a failure of the transmitting service of the B.B.C. are felt by several millions of listeners. I presume there is a certain time-lag between the time of the failure and the switching-in of the duplicate piece of apparatus, which accounts for the term "technical hitch" utilized by the B.B.C. when apologizing for a break in the transmission.

I should like to know the voltage which is induced in the stay-wires of the aerial masts. I believe a very high voltage is induced in the stay-wires at the G.P.O. station at Rugby, and on one occasion a serious accident resulted from a person making contact with a stay-wire at the anchorage insulators. Are any particular precautions taken at the Droitwich station on this account?

Mr. H. Faulkner: The paper has brought back to me recollections of the many problems with which we were dealing some 9 or 10 years ago in the design of the Rugby radio station. I am pleased to note that many of the conclusions which we came to at that time are still regarded as sufficiently good for modern practice; I am equally pleased to see that many very remarkable improvements have taken place, notably in the lay-out and design of the station. The authors were able to produce the necessary output, which, bearing in mind the modulation requirements, calls for about the same valve provision as at Rugby, with only four valves. This shows the very remarkable progress which has been made by our valve manufacturers in designing valves for wireless transmission purposes. Coming to rather smaller details, on page 206 I notice that one of the requirements was that "the Post Office buried cable circuits must be available within 3 or 4 miles of the site." I should have thought that it would have been possible to allow of much greater distances than that, seeing that it would not have been necessary to take more than a few pairs into the station. I notice that the authors have adopted the method of supplying cooling water through hose-pipes. This is a departure from the original B.B.C. practice at Daventry, in which a sprinkler was used; I have a suspicion that the sprinkler was not altogether successful, and I should like some information on that point. The use of Electroflo meters is to my mind very sound practice. The authors state that a very constant voltage is essential for the purpose of supplying the protective circuits; I cannot see why this should be so. I imagine that what the authors really mean is that the voltage should be always there, rather than constant in magnitude.

Regarding the half-wave aerial for the medium-wave station, I should be very interested to know what increase in service area has been obtained by this means. These aerials were used originally in Germany with a view to giving less radiation in an upward direction and a bigger radiation along the ground, so extending the distance from the station of the point of fading.

The method used on the mercury-arc plant for suppressing flash-arcs is very ingenious and gives a great advantage for anode supply to large transmitting valves. I am interested to see that small condensers are connected between the grids and filaments of the large valves. This feature was introduced first of all into the Rugby transmitter, and was always found to be satisfactory.

The brilliant work on the output circuit is the outstanding feature of the station, and gives to Droitwich a very definite superiority over all other long-wave broadcasting transmitters. The series-modulation system seems to be a very distinct advance.

Mr. P. N. Murdoch: The decision taken by the B.B.C. in favour of a private power supply was presumably based on considerations either of cost or of reliability. Mr. Hooper has dealt with the question of cost fairly satisfactorily, and I should like to mention reliability. As I am directly connected with the supply company affected, and responsible for the continuity of supply in that area, I should like to say that there is a duplicate 66-kV line passing quite close to the Droitwich station, and we could have given a reliable supply to the station without any difficulty. Further, there has not been a breakdown on that line for over 12 months.

Mr. H. H. Taylour: I should be interested to know what troubles, if any, have been experienced with the two independent systems of high-tension d.c. supply during the admittedly short period of operation so far completed. An installation of this description, using mercury-arc rectifiers and generators under practically identical conditions, should enable a direct comparison to be made between the merits and demerits of the respective systems.

With regard to the transmitters proper, what substantial advantage is gained by employing the somewhat elaborate aerial transmission lines and transformer houses in preference to the simpler and, one would imagine, more economical arrangement of feeding the aerial direct from the main transmitter building?

Mr. C. R. Woodward: There is ample evidence at Droitwich of the tremendous strides that the B.B.C. have made in transmitter design and technique since the days of the experimental station at Daventry.

It is interesting to note that their H.T. supply has changed from thermionic valves to mercury-arc rectifiers and high-voltage d.c. generators. I remember that Daventry 5GB had a 10 000-volt d.c. generator that could not be relied upon. The change to a closed-circuit cooling system seems to me to be a logical step.

The initial drive of the National transmitter is in substance only a plain *LC* circuit, for which the authors claim a frequency stability of 10 parts in a million, which is indicative of very good design; is the Regional transmitter controlled in the same way? It has been my experience that it is much more difficult to maintain frequency stability on the lower wavelengths without resorting to mechanical resonators or piezo-electric control.

The reflector of the medium-wave aerial is a new departure, and while it is not unusual to use a reflector on short waves I am doubtful of its efficiency on the medium wave-band. It would be of interest if the authors could include in their reply a polar diagram showing the field-strength distribution due to this aerial.

Mr. R. E. Coomber: I remember that about 12 years ago, in the early days of broadcasting, the power employed was about 1 kW, and apparently such stations as Bournemouth, London, Aberdeen, etc., were received quite well in the Midlands with this low power and with the comparatively inefficient receiving sets of that period. Since then the stations have progressively increased in power from 1 kW to 150 kW, and the service areas, apart from that of the National transmitter, are apparently the same. Under present conditions it is impossible to receive 1-kW stations at anything approaching the same distance from the transmitter as formerly—even with modern sensitive receivers. Is this diminution of transmitting range brought about by the swamping effect of the powerful stations interacting and cutting down the effective range? If so, would it not be possible by a reduction in strength of both English and foreign transmitters to give the same service area and efficiency?

Mr. F. C. Orchard (*communicated*): I should like to know whether the opinion expressed at the bottom of page 206 and the top of page 210 relating to the inferiority of mercury-arc rectifiers as compared with high-tension motor-generator sets is based on B.B.C. experience at Droitwich. If so, what factors contributed to that view being taken? If not, it would appear unfair to British manufacturers to class them with unsuccessful makers on the Continent.

If the motor-generators are operated in series how does the output wave-form compare at light and full loads with that of the rectifier equipment using a smoothing circuit? It is a pity that a timing wave was not recorded on the oscillograms shown in Figs. 12 and 13, and that a scale of values of current and voltage is not shown. These oscillograms are reduced to the level of pictorial illustrations, without the means of checking up values.

Referring to the protection of the motor-generators at times of flash-arc or heavy d.c. overload, an oscillogram comparable with Figs. 12 and 13 would have added much in interest to the paper. Furthermore, one has to read the last paragraph on the left of page 217 most carefully if one is not to draw an unfavourable comparison with the rectifier operating under similar conditions. In the one case the short-circuit is cleared in 1 or 2 cycles, while in the other the most that is done is to reduce the actual fault current to zero and substitute a short-circuit current limited by the inherent characteristics of the machine and choke. How long this condition persists is not stated. What means are used to shut down the motor-generator sets when running on artificial short-circuit? Is this system of protection used when machines are operating singly and not in series? It would appear that the shock to the generator is most severe during the time the flash-arc occurs and the artificial short-circuit is applied. It would be of further interest to know how many power-plant generators were on the busbars during the test and what was the extent of the frequency deviation. For how long was the disturbance manifest before the standard frequency was regained? Because of the severity of such short-circuits and the fact that a common power plant supplies two transmitter systems, it is somewhat surprising that the B.B.C. decided on a comparatively small private generating station. Would not the service have been less affected by having the large amount of synchronizing power which would have been behind the service lines of a local authority's system? An oscillograph record of the voltage, current, and frequency, at the generating-plant busbars at such times of short-circuit supply with two, three, or four generators in commission would have been very illuminating.

[The authors' reply to this discussion will be found on page 250.]

North-Western Centre, at Manchester, 2nd April, 1935.

Mr. T. E. Herbert: The point is made in the paper that the quality of the output is very largely dependent on the telephone connecting links between the studio and the station. It is, of course, a fact that in the use of ordinary telephone cables there are rather serious limitations as regards cut-off. In the cables employed, special circuits have been treated for the use of the B.B.C., but I foresee the day when greater fidelity will be required and the type of circuit at present provided will no longer be adequate for the purpose. There is no difficulty, other than that of cost, in providing telephone circuits which will transmit a very much higher range of frequencies than is required. For example, there is the coaxial telephone cable which is in process of development and by which an enormous band of frequencies can be transmitted. Indeed, by means of this type of cable 200 separate channels of speech can be provided on a single core. When greater fidelity is required, broadcasting will go through the same stages of development as the gramophone went through.

Will the authors tell us whether they have yet contemplated the use of the demountable valve which was recently developed in Manchester, and which gives an output of something like 500 kW?

Mr. G. F. Sills: I have had the privilege of visiting the North Regional Station at Moorside Edge, and one of the things that I remember is that arrangements have been made to enable a current of 300 amperes to be put into the aerial with the idea of melting any snow or ice. Is this provision necessitated by the height and location of the site, and is the same procedure necessary at Droitwich?

One of the authors' slides showed a transformer house near the aerial, and lightning arrestors were in use. It would be interesting to know what the air-gap is set at to achieve the desired purpose.

Mr. F. Roberts: With reference to the series-modulated amplifier, I should like to know the actual value of the total capacitance to earth from the filament-heating generator and its associated equipment, including the grid-biasing device. On the occasion of last year's visit of the Wireless Section to Droitwich, I was told that this capacitance was of the order of 100 $\mu\mu$F. Since the capacitance between two concentric spheres of radii 0·5 and 1 metre respectively, to which the generator and surrounding earthed objects roughly correspond, is approximately 100 $\mu\mu$F, this figure appears to be very small for the total capacitance referred to in my question.

I should also like to know whether the bald statement that distilled water is used for cooling the anodes may be taken as implying that distilled water is a perfectly satisfactory cooling agent, and that no troubles are encountered in its use.

Mr. F. W. Taylor: The authors describe at length the apparatus and working of the various sections of a modern broadcasting station. It occurs to me that however important these parts may be they could not function at all without the connections between sections and between the component parts of one section. As a large portion of the apparatus involves high d.c. potentials, and in view of the serious effect of breakdown, it would be interesting to have some information on how far it is preferable to use bare h.t. connections and how far to use insulated cables. Also, in view of the special nature of dielectric phenomena under d.c. conditions, I should like to know whether the authors have experienced any difficulty due to sealing-end troubles or the accumulation of dust, which always occurs when a point is maintained at a high negative potential with respect to earth.

Mr. F. Jones: Referring to the descriptions of the master-oscillator units, the designers have apparently decided in favour of this method of control as against a crystal-controlled drive. The master-oscillator method has the undoubted advantage of permitting a rapid change of transmitted frequency, and the frequency stability mentioned—10 parts in a million—compares very favourably with that obtainable with a crystal drive. The precautions required to maintain this accuracy, however, appear somewhat elaborate and a great deal depends on the particular valve in use. The necessity for maintaining the valve filament continuously heated might be expected to lead to frequent replacement of the oscillator valve, involving difficult frequency adjustments with each new valve.

An interesting point which arises in connection with the speech-input arrangements is the relation between the variations in volume of the programme being transmitted and the corresponding variation in amplitude which can safely be applied to the transmitter, and the means of controlling this input. Experience in the reception of, say, an orchestral programme, indicates that the manual control, which is presumably employed, sometimes give rise to irregularities in the volume received, on account of the obvious difficulty of following, by hand, the variations of volume encountered. It would therefore appear that some form of automatic gain control would be desirable, and perhaps the authors could say whether such a method has been considered.

Mr. W. Fennell: I feel that perhaps in 10 years' time the number of units of generating plant of various kinds will be rationalized, and there will be three or four, just as in a power station. Some means may be found of simplifying the plant so that it will not cost so much. The B.B.C. apparently are very keen on costs, especially in regard to the generation of power.

I sympathize with the authors in the difficulties they have encountered owing to the site being in a salt area. In Northwich we also have trouble from subsidence due to the existence of brine pumping. I note that the paper refers to " an extensive subterranean brine stream, which flows for several miles through the district which is otherwise the most suitable"; I should like to know where that stream rises, and where it runs into the sea. The authors must mean that as there is brine pumping in Droitwich, and as subsidence follows brine pumping, they had to take care they did not put the station where there is rock salt.

One point of national importance, in my opinion, is in regard to power plant and power generation. The authors put forward very weak arguments why the B.B.C. should not patronize another big corporation of a semi-Government type, namely the Central Electricity

Board. They say that reliability is of great importance and that they must not depend upon anybody else. This means that they must have a power station of their own, quite detached, and very unkindly they say that it is probably cheaper than buying the energy from the national supply. They might at least have adopted the alternative scheme of taking half the energy from the public supply and the other half from their stand-by plant. I do not accept their figures as to cost, because I happen to have been responsible for the running of Diesel engines and know that actual costs often greatly exceed estimates. Taking Mr. Kennedy's figures* for 50 per cent load factor, which is about what the station will run at (roughly 12 hours per day), the oil-engine all-in cost comes out at about 0·7d. per unit; allowing 10 per cent loss, the grid price is 0·4d., and adding to this sum a profit equal to one-third of that prime cost, we get a competitive figure of 0·53d. In the paper referred to, Mr. Kennedy proved that—by reason of the very low grid unit price of 0·2d. per unit—the higher the load factor the bigger the advantage of buying from the grid.

I should like to know how much the power station cost, and the annual cost of running it. In other words, how much per kWh does it cost to run the plant, and what is the load factor? It may be that these figures will justify what the B.B.C. have done, but at present I suggest that they have not proved their case.

With regard to the general policy of having an independent plant, because of the presumed importance of B.B.C. broadcasts, failures are not unknown. We do not know how many are due to power plant, but I suggest that very few would be due to failure of the public supply. Normally, however, very great reliability is not required from any one station of the B.B.C. Even if Droitwich did fail, the public could quickly tune in to another B.B.C. station.

Mr. G. G. L. Preece: It would be interesting if the authors could let us know what is the practice of some of the foreign stations, say in Germany, in regard to power supply. Do they have their own power plant, or do they take the power from their " grids"?

With regard to the use of mercury-arc rectifiers with grid control, this does increase the ripple effect quite a lot, and it would be interesting to know whether any special smoothing device is employed in connection with this which stops any ill-effect on the transmitter.

Mr. A. H. Gray: I notice that two of the CAT valves are housed in each cubicle, the third being only brought into action in the event of a breakdown. Bearing in mind the care with which these valves are transported and housed, it would appear that some considerable time must elapse before a valve can be fitted, and a further delay must occur whilst the filament is brought up to the correct working temperature.

Have the authors any particular scheme whereby this time can be materially reduced, and furthermore what is the order of this delay?

[The authors' reply to this discussion will be found on page 250.]

NORTH-EASTERN CENTRE, AT NEWCASTLE, 8TH APRIL, 1935.

Mr. F. G. C. Baldwin: The paper indicates the remarkable advances which have taken place in the art and science of broadcasting since its inception. It also shows that the present-day communication engineer has to deal with power units of no small size.

In the early days of broadcasting, studios were situated in close proximity to the broadcasting transmitters; modern conditions have necessitated that studios should be placed more conveniently for artists, and transmitters situated in positions ideal for their purpose. This has been rendered feasible by the utilization of circuits in underground cables provided and maintained by the Post Office Engineering Department, and there is a considerable network of such circuits now in use by the British Broadcasting Corporation.

Long-distance telephonic communication exclusively over underground cables has developed in a remarkable way along with the development of broadcasting, and has assisted greatly in the satisfactory distribution of programmes and in ensuring their reliability. The use of underground-cable circuits for broadcasting has necessitated the provision of telephone lines superior to those customarily used for speech, i.e. lines which will transmit the greater range of frequencies required for the satisfactory reproduction of music and other sounds. In addition to these lines provided exclusively for the British Broadcasting Corporation the Post Office system of communication is in constant use for various broadcasting purposes, and there is active co-operation between the B.B.C. engineers and the Post Office engineers.

On page 207 the authors say that to generate power locally is as cheap as, if not cheaper than, to buy from the public supply mains. I should like to know what is the factor which makes this so. Is it the remoteness of the transmitting station from the electric supply mains, and the cost of the power transmission line?

The authors mention that mercury-arc rectifiers, although not so reliable as motor-generators, are employed for the high-tension supply, largely, I suppose, because of their higher efficiency. I gather that they were installed more or less experimentally, and it would be interesting to know whether the decision to employ mercury-arc rectifiers has been justified in practice and whether any breakdown has occurred or any particular difficulty been encountered.

On page 225, certain smoothing arrangements are indicated which appear to me somewhat inadequate, and I should be glad if the authors would say whether these are the only precautions found necessary to prevent ripple.

The low field strength at Newcastle is mentioned on page 233, and a possible reason is assigned for it. When the Droitwich long-wave station was first opened we in this locality suffered considerably from fading and distortion. Although the trouble still occurs it has largely disappeared, and it would be interesting if the authors would tell us whether the improvement observed may be attributed to natural causes or whether it is due to improvements introduced at the transmitter.

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* *Electrical Supervisor*, 1934, vol. 14, p. 178, diagram No. 9.

Mr. William F. Smith: The authors may have felt some trepidation in accepting the invitation to read their paper before this Centre, situated in a city that can boast of a field strength from Droitwich of only 6 millivolts per metre. It must be remembered, however, that they were set the colossal task of satisfying some 15 to 20 million listeners located in dense groups a considerable distance apart. When the question is viewed from this angle it must be appreciated that considerable success has resulted from their efforts.

The authors rather infer that the band width of the B.B.C. transmitter is limited by the poor response of the Post Office lines connecting the studio and transmitter. The P.O. lines are capable of satisfactorily transmitting up to 7 000 cycles per sec., representing 14 kilocycles per sec. in the ether after the modulation stage has been passed. International agreement limits the separation between stations to 9 kilocycles per sec., and therefore the transmission of any band greater than 9 kilocycles should not be necessary. The transmission of a wider band may, of course, be desirable for listeners near the transmitting station, but considerable interference is likely to result for listeners not so favourably situated, owing to overlapping wavebands.

I do not agree that a considerable amount of fading can occur without the average listener being aware of the fact. He may not recognize the phenomenon as fading, but the reduction of signal/noise ratio which results from fading causes a change of listening conditions which cannot fail to be observed. Sets fitted with automatic volume control are not immune from this trouble if the normal signal/noise ratio is low.

It would have been useful if the paper had included a field-strength polar diagram under night conditions, for comparison with the daylight diagram, in order to indicate the relative fading in various directions.

The fading on Droitwich which was experienced in this area on the opening of the station, appeared to be of a selective character, and perhaps the authors can say whether their experience is that selective fading is very pronounced. My experience has been that the fading of the Droitwich transmissions has been very much reduced during the past 2 months.

The provision of a filament-heating generator for each water-cooled valve in the long-wave transmitter seems a costly and unnecessary elaboration. The isolation of the spare valves could be easily and quickly performed by means of isolating switches. There would appear to be no gain in regard to "continuity of service" resulting from the provision of the extra machines.

The principle of providing plant, including spares, of such a character that flexibility to suit all eventualities is attained, seems to have been departed from in the provision of high-tension supplies for the medium-wave-transmitters. The two 12 000-volt machines for this purpose were specially designed and constructed with insulated cores, and must have been very costly. Would it not have been better from the point of view of flexibility, and possibly cheapness, to use, say, four 6 000-volt machines connected in series as required? In an emergency, when these machines were in use for the long-wave transmitter three of them in series would probably suffice (on a reduced power output), thus leaving one machine as a stand-by.

The insulation of the machines from earth as a whole would appear to be an easier proposition than insulating the core from the shaft, and perhaps the authors will say what were the reasons which led to the adoption of the higher-voltage type of motor-generator.

It is interesting to find that in these days of rapid development of radio valves, a place can still be found for a valve which must have been developed some 15 or more years ago. I refer to the LS5 valve employed in the master-oscillator stage. The "life" of these valves is remarkable; I know of a case where one of these valves exhibited characteristics almost as good as new after 4 years' use for 20 hours per day.

The type of volume indicator on the speech-input circuit is interesting. Why is the standard of volume termed "zero volume"? The more usual term is "reference volume." Presumably the method of operation of the meter is that it integrates a voltage between some fixed voltage value and the peak voltage. Can the authors give the approximate period over which such integration takes place, and say how the fixed value (which presumably does not operate the meter) is decided upon. What percentage modulation does this figure represent?

It is observed that the equalizer is placed directly in the Post Office line without the intervention of a line amplifier. The level of the programme at the control potentiometer is of the order of 16 decibels below zero volume, and it would seem that cross-talk and power hum are likely to be picked up on the gain control.

The method of lighting the masts and at the same time retaining insulation from earth as far as high frequencies are concerned is interesting, but I do not see the necessity for the centre pair of coils between earth and the mast structure.

What is the "make-up" necessary in the distilled-water circulating system? I should like to conclude with just one other question: What is an "average" receiver?

Mr. H. V. Field: The authors state that the reliability of high-voltage mercury-arc rectifiers is, at the present stage of development, inferior to that of motor-generators. What are the troubles that have been experienced in Continental stations using such rectifiers? Does the experience gained at Droitwich up to the present confirm the above statement?

Induction-regulator control of voltage on these rectifiers is preferred to grid control, although the latter is simpler, cheaper, and able to cover the same range. The wave-form on the output side deteriorates with reduction of voltage when grid control is used, and a greater degree of smoothing is required than would be necessary with induction-regulator control. Is this the reason for the selection of the first method?

The master oscillator is designed for 100 kilocycles per sec. and frequency-doubling is employed to give the required 200. Why is this method preferred to direct operation of the oscillator at 200 kilocycles per sec.?

The earthing system would appear to operate as much as a counterpoise as an earth. The size of the earth wire (No. 16 S.W.G.) seems rather small. What determines the wire size employed, and is it a compromise between surface area and high-frequency resistance? Have any difficulties been experienced resulting from corrosion on these small wires?

The 150-kW valves are presumably of the directly heated type. What type of filament is used? Have indirectly heated cathodes been developed for such work? These would permit the use of a higher voltage for the heater, which would be preferable for both construction and operation.

In some Continental systems the mast has been used as a vertical aerial. How do the characteristics of such a system compare with those of normal types of aerials such as are used at Droitwich?

The conversion efficiency of the final stages of the transmitter only reaches 33 per cent. Methods are being developed, using constant modulation depth and variable carrier amplitude, which give a much higher efficiency. Are such schemes satisfactory in practical operation?

Captain F. W. Gaskins: I should like to ask whether any serious trouble has been experienced due to low insulation of the aerials. No doubt tests are made from time to time, and it would be interesting to know within what limits the insulation resistance varies. What is the lowest figure for satisfactory working, and is it found that an extremely high figure—if this is ever obtained—produces any better results than a moderately high one?

It would be interesting to know how the masts stand the climatic conditions. Are they treated both at the works before dispatch and also after erection, and, if so, what with? How long is it before they have to be treated again?

With regard to fading, those speakers who have mentioned that they do not notice any trouble of this sort must employ receivers equipped with all the latest improvements, and reside where these effects are not noticeable (if this is possible). I notice both fading and distortion of the Droitwich programmes, and many of my friends report similarly.

Mr. A. G. McDonald (*communicated*): On page 204 the authors state that the service frequently becomes unacceptable on account of fading during the hours of darkness. Surely service-area, as distinct from long-distance, reception is largely governed by the angle of propagation of the radiation. If a high-angle radiation is used fading will be severe at distances where this radiation reflected downwards becomes out of phase with the horizontally projected wave. The angle of radiation has been investigated and controlled in the case of short-wave aerial systems, e.g. beam antennæ, but the problem of providing low-angle radiation on long-wave aerials has only recently received attention. It is known that various Continental stations have been experimenting with special aerials intended to give this type of radiation, and perhaps the authors would say whether they have any knowledge of these experiments.

On page 212 the method of laying the earth connection by the use of a plough is described. This method was first used at Leafield radio station, and a development of this system has resulted in the laying of multi-core telephone cables by a mole drainer. What is virtually a furrow is cut, the cable is drawn in, and then the sods are turned back.

The B.B.C. have found that the h.t. motor-generator is very reliable. The Post Office also have experienced trouble-free service from the 18 000-volt d.c. motor-generators at Rugby radio station. Except on the score of efficiency there is little to be gained by the adoption of mercury-arc rectifiers.

It is rather surprising to find that the B.B.C. rely on a master oscillator in these days of piezo-electric crystal and tuning-fork drives. Presumably a control within 1 part in 100 000 is good enough for the service required, and quick changes of wavelength may be required.

I note that distilled water contained in a copper-pipe system is used for the cooling of anodes and filament seals of transmitter valves. Is it too early yet to say whether any noticeable erosion has occurred? At Rugby radio station pure distilled water had such a solvent action on iron pipes that many lengths had to be renewed, and some tons of sludge had to be removed from the tank. Rain water was afterwards used in place of distilled water as being sufficiently pure while at the same time being less active chemically.

One of the most interesting statements in the paper is contained on page 232, where the authors say that in early tests of this type the effective height of the aerial was measured and the measured value was found to give incorrect results. In view of the fundamental importance of experiments of this character, on which relatively little information has been published, I suggest that the authors might be asked to give the results of their experiments in amplified form in an additional appendix. Perhaps the authors would say what was the method of measuring the effective height. If it was measured by the usual method of transmitting energy from the aerial and then measuring the field strength at a number of points situated some distance outside of the range of the inductive field, then it would seem that if by so doing incorrect results were obtained the whole basis of the known laws of radio energy propagation require modification.

[The authors' reply to this discussion will be found on page 250.]

SCOTTISH CENTRE, AT GLASGOW, 9TH APRIL, 1935.

Prof. G. W. O. Howe: In the oscillogram of Fig. 6 (Plate 1), which purports to show the excellence of the wave-form of the alternator, it looks as if a high harmonic were superimposed on the wave. Is this really a harmonic? As the frequency appears to be about 2 000 cycles per sec. I suspect that it is really due to a faulty oscillograph.

The portion of the paper devoted to a description of the arc rectifier is very valuable, quite apart from any wireless application, dealing as it does with various aspects of the problems that arise in connection with any application of the arc rectifier.

Turning to Fig. 25, I suppose that the only variables here are really the frequency and the resistance, and I presume that from the curve one could calculate the inductance and capacitance of the aerial.

There is an uncomfortable air of compression about the paper. In particular, I think that if the Appendix were made twice as long, it might thereby be made ten times more intelligible and interesting. A similar remark applies to the explanation of Fig. 27. In Fig. 26, for example, there are many cases of two condensers connected in series, such as C_{21}, C_{22}, etc. In Fig. 27 they are replaced by condensers of $2C_{21}$, $2C_{22}$, etc., and not, as one might expect, by condensers of $0 \cdot 5C_{21}$, $0 \cdot 5C_{22}$, etc.;* but no reason appears to be given for this. One is left to infer that Fig. 27 represents the two sides of Fig. 26 connected together in parallel, the earth forming the other terminal, in which case it is to be hoped that the values of L_{11}, etc., have also been suitably modified.

Mr. J. Greig: I should like to ask one or two questions in regard to the high-frequency output stage of the transmitter. As the use of two CAT14 valves in each side of the push-pull circuit in place of a much larger number of CAT6 valves in parallel represents a fairly drastic change in practice, it would be interesting to know whether the tuning-up troubles due to instability and parasitic oscillations were materially different from those usually encountered with the older arrangement. I understand that valves of the CAT14 type, when run singly under works test conditions, have been found to be entirely free from flash-arc troubles. It has, however, been demonstrated by B. S. Gossling that any tendency to flash-arcing is accentuated when valves are run in parallel on H.T. supplies of relatively large power capacity; I should therefore be interested to know whether any such discharges have so far been encountered at the station.

Mr. J. A. Cooper: On page 218 it is stated that each generator is connected directly to the associated valve filament without switchgear. Are protective devices included in the connection? If not, perhaps some statement could be made as to whether any trouble is likely to arise in the valve circuit, and, if so, as to what is likely to happen.

Referring again to page 218, it is stated that " The machines possess a self-selecting feature which operates as follows: Each generator is provided with a 2-pole contactor, also highly insulated from earth, which is energized from the exciter terminals and closes as soon as the machine is started." I should be glad if the authors would explain this arrangement more fully.

I should like to know why the designers departed from the practice of using in " C " units banks of valves in push-pull, and employed instead pairs of large valves which are individually far more costly. Finally, perhaps it would be of interest if the authors would explain in detail what is shown in Figs. 12 and 13.

The Authors' Reply to the Discussions at London, Birmingham, Manchester, Newcastle, and Glasgow.

Sir Noel Ashbridge, Mr. H. Bishop, and **Mr. B. N. MacLarty** (*in reply*): Colonel Angwin raises the question of the use of aerials directional both in the horizontal and vertical planes. With regard to the former, we do not consider it desirable to give a directional effect towards the north to improve the service to Scotland, since the strength given in the south-west and along the south coast is by no means more than adequate. As to directivity in the vertical plane, this is a question which has been much discussed by radio engineers all over the world during the past few years. While it is now generally admitted that for medium waves an aerial can be designed which will project a high percentage of the energy at a small angle with the horizontal plane, the difficulties become considerable when an attempt is made to apply the same principle to long waves. There is, however, in existence a design which it is claimed will achieve a similar object. This involves the use of a large number, say 6 or 8, of high masts, and a very large area of land. It is stated that this system is to be tried in Germany, but the cost is admittedly very high indeed, and it has not yet been proved that the results are in proportion to the cost.

With regard to the comparison between the power consumption in the case of series modulation and high-power modulation, it is presumed that Col. Angwin has in mind high-power class B modulation. If this is the case the figures for relative power consumption would be of the right order, although his estimate of 1d. per unit for power is about 50 per cent too high. If, however, reference is being made to class A modulation in comparison with series modulation, it will be found that there is no appreciable difference between the two from the point of view of power consumption. The class B modulation system was not adopted when the station was being designed, since it had not been proved to our satisfaction that the distortion when using this method would be sufficiently low.

Col. Angwin and several other speakers have raised the question of the reliability of mercury-arc rectifiers for the high-tension d.c. power supply. When it was decided to install mercury-arc rectifiers it was realized that there might be trouble from " back firing " with such equipments working at this voltage. Nevertheless, it was anticipated that the interruptions arising from this cause would be brief, and sufficiently infrequent not seriously to affect the service. However, on account of a certain degree of uncertainty as to the performance of these rectifiers, it was decided to use mixed plant, consisting of mercury-arc rectifiers and high-tension motor-generator sets. The object in view in attempting to use mercury-arc rectifiers was to obtain improved efficiency coupled with a considerably lower first cost. At the time of writing it cannot be said that the performance of the mercury-arc rectifiers compares with that of motor-generator sets from the point of view of reliability, but experimental work is still in progress with a view to eliminating a tendency to " back fire."

With regard to Col. Angwin's query concerning an apparent discrepancy between the total resistance of the aerial and tuning circuits, which is given as 20·4 ohms, and the effective height, which is given as 167 metres, it is admitted that these two figures do not check up, but it is stated on page 232 that ". . . the effective height as calculated from field-strength measurements was found to give unreliable results." The value of 20·4 ohms given for the total resistance of the aerial and tuning circuits is a measured value on which the overall efficiency measurements of the transmitter have been based.

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* Corrected for the *Journal*.

In reply to Mr. Ditcham's remarks concerning the relative advantage of the transducer circuit as compared with an ordinary tank circuit, the advantage of the former does not consist of a greater suppression of harmonics, but lies in the improved performance of the transmitter at the side-band frequencies corresponding to high modulation frequencies. These advantages will be found described on pages 226 and 235 of the paper.

Mr. Eckersley raises the question as to whether the saving in power costs when using rectifiers is justified. He gives a figure of £625 per annum, and compares this with the cost of programmes. Without considering in detail the figures which he has taken, it should be observed that it is, perhaps, not sound to ignore a saving because it happens to be small in relation to a totally different class of expenditure. He also makes a statement that there is no saving in capital cost, since it has been considered necessary to use two machines in any case. It must be borne in mind, however, that if the mercury-arc rectifiers had not been installed it would have been necessary to install at least three more motor-generator sets, the cost of which would have been several thousands of pounds in excess of that of the mercury-arc rectifiers.

Mr. Eckersley asks our opinion as to what supply is likely to be used in the future for voltages of the order of 40 000–60 000. We are of the opinion that it is by no means demonstrated that voltages of this order are likely to be used for thermionic valves; in fact, judging from a recent German design of high-power valve, it seems that voltages may go down to the order of 10 000 volts. If, however, high voltages should be required for wireless stations, it would seem that some form either of mercury-arc rectifier or of hot-cathode rectifier is likely to be developed for this purpose. It should be pointed out, on the other hand, that thermionic rectifiers become an economical proposition at high voltages with proportionally small currents.

Mr. Eckersley raises the question of interstage band-pass filters, and inquires why there should be any difficulty in designing these for low-power modulation. The design of the interstage circuits, the output circuits, and the transducer circuits, was examined in the light of network theory, and it was not found possible to use filters of the well-known band-pass type, such as are used in low-power telephone circuits, since the design of such filters is made without any regard for the currents or voltages which may be produced across the circuit. Further, a number of filters in the interstage circuits would be complicated to adjust. For this reason it was found necessary to introduce circuits of a modified design. In brief, ordinary band-pass filters which would be suitable for low power would not be suitable where a considerable amount of power is being used.

With regard to the query as to why a.c. lighting was not used for the filaments of the high-power valves the answer is that it was considered that there was a risk of a hum on the carrier.

As to whether the position of Droitwich has adversely affected reception in the south-western districts and Northern Ireland, owing to shielding by the South Wales mountains and the Pennines respectively, the fact remains that the fields in the two areas mentioned bear the normal relationship to the powers of Daventry and Droitwich. Moreover, there is no marked difference in the fading of this station in any one particular direction.

Mr. Eckersley comments on the fact that distortion corresponding to 4 per cent of the harmonic should exist in a modern station such as Droitwich. It is well known to designers that it is a matter of great difficulty to reduce the harmonic content at the output of a high-power transmitter to a value of less than 4 per cent at high modulation levels.

Regarding the comparison between open feeders and tubular feeders, no troubles have been experienced due to open feeders at the Droitwich station. We agree that in certain circumstances the use of tubular feeders is desirable.

In reply to Mr. Strong's question concerning bass distortion due to the impedance of the smoothing circuit, there is no doubt that a certain amount of distortion due to this cause is introduced below 400 p.p.s. The fact remains, however, that no obvious distortion is detectable, and for this reason a close investigation has not been made. The frequency-range over which the measurements of harmonics at 90 per cent modulation were taken was from 500–1 000 p.p.s.

In reply to Mr. Shams-el-Deen's question, we do not agree that the phase-modulation system is superior to that used at Droitwich. Moreover, it would appear doubtful whether any saving in power is obtainable in actual working.

Dr. Hughes inquires as to the objection to correcting the characteristic of the audio-frequency input to accentuate the high frequencies above the linear characteristic by the use of a transducer, with the object primarily of saving the power lost in the latter. The first point which arises is that the power lost in the latter and the aerial circuits amounts only to 5 kW. Moreover, it has to be remembered that the function of the transducer is not only that of correcting the frequency characteristic of the station. In any high-power station it is essential to incorporate some form of network to prevent the radiation of harmonics, and the transducer circuits fulfil this purpose also. Finally, it is doubtful whether it would be feasible to incorporate correcting circuits in the audio-frequency amplifiers to accentuate the high frequencies sufficiently to give an aerial response comparable to that attained with the use of the transducer circuits without running into design difficulties due to excessive voltages at the higher side-band frequencies.

In reply to Mr. Gracie, the time required for adjustment of the transducer circuits would be of the order of 2 hours. The object of adopting a variable oscillator circuit as a means of generating the carrier frequency is more on account of minor changes of frequency not greater than 500 p.p.s., which would not normally require a readjustment of the transducer circuits.

In reply to Mr. Voigt, the frequency characteristic on page 234 extends to 7 000 p.p.s. Frequencies beyond this are in any case not transmitted by the telephone cable circuit and are therefore of very small interest.

Mr. Parsons inquires why the level of the radiated higher frequencies is not raised in order to compensate for cut-off in the receiver. Apart from the question as to whether such a procedure is sound from the point of view of the receiver designer, difficulties would probably be encountered in the design of the circuits of the transmitter, due to excessive voltages at the higher modulation frequencies.

Mr. Dransfield asks the cause of fading from Droitwich at certain ranges. Fading is, of course, due to interaction between the direct (or ground) wave and the indirect (or reflected) wave, and where the distance is such that the field strength of the two is comparable then fading will be observed. It is inevitable with practically any transmitter, even those using anti-fading aerials, that this condition will obtain at a certain distance which will depend first of all on the attenuation of the ground wave, and secondly on the angle to the horizontal at which the greater part of the radiation energy is projected. In the case of medium wavelengths it is now usual to adopt some type of aerial which has the effect of transmitting the energy at a low angle, thus causing serious fading to occur at the maximum possible distance. The difficulty of applying this procedure to long waves has already been mentioned in reply to Col. Angwin.

The fading from Droitwich during the mid-winter of 1934–35 was certainly troublesome, particularly since it frequently took the differential form. It is thought, however, that the Heaviside-layer conditions during this period were, to an extent, abnormal, although it is admitted that such conditions may exist during next winter. It has been established that the fading characteristics of Droitwich closely resemble those of several other similar long-wave stations on the Continent, and although these stations use widely different forms of aerial (not of the anti-fading type) the behaviour showed remarkable similarity. The outstanding difficulty with regard to the fading question lies in the fact that it is differential in nature. If this had not been the case, modern automatic volume controls would largely have obviated the trouble.

It is not possible to explain fully the method of lining-up modulation, as this would go considerably outside the scope of the paper, since modulation control is primarily effected in conjunction with the studio apparatus.

Mr. Hooper and several other speakers inquire why a private supply is used in preference to purchasing power from public supply mains. He assumes that the cost of the private supply would be not less than 0·52d. per unit as against about 0·5d. from the national network. We do not disagree with these figures, but Mr. Hooper has overlooked the fact that the designers of the station had instructions to take such steps as were necessary to make the station capable of operation without taking power from an external source. This left two alternatives:—

(1) To install station plant to generate power at all times on the station, or

(2) To take power from the public supply and install stand-by plant.

If a suitable amount related to the cost of the stand-by plant is added to the unit cost it will be found that no economy is effected in taking power from the public supply.

In reply to Mr. Partridge, the mast insulators were not tested by means of high-frequency potential while under mechanical stress. With regard to the electrical test, it is usually found that, provided there is no appreciable heating due to electrical losses in the porcelain, there is little danger of breakdown, nor is the mechanical strength affected by the presence of the high-frequency potentials.

Grid control of rectifier voltage was not used, as there was some doubt at the time of designing this plant whether such a method of control would give rise to subsidiary troubles.

The question has been asked as to what receiver was used when the minimum field strength was fixed at 2·5 millivolts per metre. With modern receivers the minimum field strength for acceptable quality of reception depends only slightly on the type of receiver used, and mainly on the ratio of signal to unwanted noise. The figure of 2·5 millivolts per metre can only be taken as an approximation, because noise intensity varies enormously from the extremes of open country on the one hand to an industrial city on the other.

The method most commonly used to measure frequency with great accuracy is by tuning-forks in conjunction with multi-vibrators. Space will not permit of a description of this method, which is well known.

With regard to Mr. Partridge's last question, long tubes are used for introducing the water supply to the valve jackets, as otherwise the d.c. anode voltage would, in effect, be short-circuited to earth. The length of tube has to be made considerable in order to reduce the leakage of current to a figure which will not cause trouble due to electrolysis, quite apart from the question of inefficiency.

In reply to Mr. Rawll, it is difficult to measure the exact voltages introduced into the stay wires, and this has never been done. Some attempt at calculation, however, was made originally. In any case the voltages across the stay wires are not high, since the voltage across the mast insulators has been measured as 3 000 volts (peak). As regards the danger of shock, the first insulator is placed about 50 ft. from the ground and the length of stay connected to the anchor block is earthed.

In reply to Mr. Faulkner, the method of spray insulation for the valve-cooling water supply was abandoned several years ago, mainly because it causes severe aeration of the water, which in turn leads to deposit troubles, and because it is not a simple matter to maintain a suitable pressure in the water jackets.

The reason why a constant voltage is necessary on the Electroflo meters becomes apparent if reference be made to Fig. 31. It is agreed that if it had been feasible in this particular station to operate the meters from alternating current then a constant voltage would have been unnecessary.

The gain in range to be obtained with a half-wave aerial as compared with a quarter-wave aerial is a controversial question. Figures have been put forward showing as much gain as 35 or 40 per cent, but it should be realized that the gain in range depends very much on the wavelength and on the nature of the country which has to be served. In general it may be said that a gain in range of between 20 and 30 per cent may be expected.

In reply to Mr. Taylour, it is mentioned in the paper that the motor-generator method of generating high-voltage direct current is looked upon as more reliable, but less efficient and more costly. Up to the present this has proved to be the case in practice.

Mr. Orchard raises a similar question. It is generally admitted that a mercury-arc rectifier working on a voltage of 20 000 is liable to suffer from "back-firing."

There are several objections to bringing the down-lead straight into the building. First, it is difficult to design a satisfactory earth system with a large building immediately under the down-lead. Secondly, the presence of a large building would reduce the effective height of the aerial. Thirdly, it complicates the choice of position for the masts, and finally it has to be borne in mind that in any case the mast has to carry two separate aerial systems.

In reply to Mr. Orchard, the ripple of the h.t. motor-generators is extremely small, both on light load and full load, even without a smoothing circuit, although the latter has to be included for other reasons. In the case of the mercury-arc rectifiers, the figure reaches approximately 4 000 volts (peak) when working with an output voltage of 20 000, but the smoothing circuit which is necessary for other reasons reduces the ripple to a negligible value.

The question regarding the timing wave on the oscillograms is not understood, since the oscillograms referred to show the d.c. output of a 6-phase rectifier supplied by 50-cycle mains. These oscillograms were reproduced to indicate the effect of the smoothing inductance (connected in series with the d.c. output) upon the operation of the control grids.

Mr. Orchard mentions that an oscillogram showing conditions when the h.t. motor-generators are short-circuited is not reproduced. Fig. 16 shows this condition, but, unfortunately, the original oscillogram was of a type which could not be reproduced photographically.

The short-circuiting device used in conjunction with the motor-generators reduces to zero the short-circuit current through a defective valve in 0·02 sec. from the moment of the inception of the fault. The current in the armature and choke circuit persists for a considerable period, but this is of less importance and does not indicate that the generator is supplying energy for this period, since the shunt field is broken soon after the armature is short-circuited. The current which continues to flow in the armature circuit is due to the energy stored in the 5-henry inductance.

The designers of these generators do not consider them to be overstressed by the application of a short-circuit and, as stated on page 217, it is impossible to produce, in any part of the circuit, voltages higher than the initial voltage due to the generators themselves.

The tendency for the energy in the smoothing inductance to keep current flowing for a considerable time is shown also in the case of the rectifiers in Figs. 12 and 13. This is a serious matter, since it tends to neutralize the advantages of grid control. It is probable that the short-circuiting devices used with the generators will, in the near future, be connected to operate with the mercury-arc rectifiers.

In reply to Mr. Woodward, the same form of *LC* drive is used for both transmitters at this station. No polar diagram has been published for the Midland Regional transmitter, as it has not yet been finally decided what adjustment of the reflector shall be adopted.

We do not agree with Mr. Coomber that the range of a modern 50-kW transmitter is not greater than that of a 1-kW transmitter some years ago. We suggest that amongst other things he is overlooking the quality of reception. A higher degree of noise was then accepted by listeners without complaint. Nevertheless, it is agreed that the range of a 50-kW station in these days is less than it should be, on account of the fact that the channel space allowed internationally is insufficient and the limit of range of a station depends very largely upon the degree of selectivity which the receiver possesses, if we neglect the question of fading.

In reply to Mr. Herbert, the use of demountable valves was studied very carefully indeed, but it was considered that for a service station insufficient experience had been obtained with these valves.

In reply to Mr. Sills, ice-melting plant was not adopted for Droitwich as it was considered unnecessary in this particular location. The lightning arrestor on the aerial is set to flash over at about three times the peak working voltage.

In reply to Mr. Roberts, the capacitance value to earth of the two filament-heating generators and all associated circuits is $0 \cdot 0015\,\mu$F.

Distilled water cannot be looked upon as an entirely satisfactory medium for valve cooling, but it seems to be the best available at present.

With regard to Mr. Taylour's question on the possibility of breakdown of high-tension cable under d.c. conditions, a large amount of ozone-proof rubber cable has been used without breakdown or deterioration in B.B.C. stations. Bare h.t. connections are used within the transmitter units.

It is not practicable in this reply to deal with the whole question of the manual control of musical programmes, raised by Mr. Jones. This is a matter not directly concerned with the Droitwich transmitting station, but is a problem of design of studio apparatus. However, it may be said that the automatic methods of carrying out this function have been carefully considered. Suggestions have already been made which, on paper, appear to be satisfactory, but they are complicated and difficult to maintain in service. Human control has the advantage of being able to anticipate sudden variations in volume. This does not mean, however, that the problem is likely to remain permanently insoluble.

We do not agree with Mr. Fennell's figures for oil-engine generation; the unit charge is about 20 per cent too high, even after making generous allowances for depreciation and interest. It must be remembered that the load is an unusual one. It remains practically constant for 15 hours a day, for 7 days a week, without interruption. In such circumstances the generating plant can be designed to operate continuously at maximum efficiency. With regard to his contention that great reliability from one station of the B.B.C. is not necessary, it has to be remembered that a vast number of listeners are in the habit of listening to the local station only and may not know how to tune-in any other station. Moreover, in the case of Droitwich there are approximately 15 per cent of the population who are not within the service range of another station.

At the time of writing, no programme time has been lost in 6 years due to power-supply failure at any of the five B.B.C. stations operating from private plant.

In reply to Mr. Preece, there are stations abroad which use an independent power supply, but it is admitted that the majority do not do so. On the other hand, in many cases independent power supplies are being installed—in some stations to supply power at all times, and in others as a stand-by. The transmitter smoothing circuits are described on page 225 and illustrated in Fig. 24.

In reply to Mr. Gray, the time required for switching in a new CAT14 valve is determined by the time required to bring the filament current to a maximum, and this at the moment cannot be reduced below 2 minutes. The arrangements which have been made to avoid the time being greater than this, owing to other causes, are described in the paper.

Mr. Baldwin's first two questions have already been dealt with. The smoothing arrangements described have proved adequate in practice. The reduction of fading to which he refers is, unfortunately, due more to a change of season than to anything else, although many experiments were made at the station with the object of reducing this fading when it was at its height. No appreciable results were, however, obtained. It is not known whether the fading will be as severe next winter as it was last, but there is reason to fear that this will be the case—particularly since the fading was noticeable over the whole of Europe and was definitely not due to any peculiar local conditions at either the transmitting or receiving ends.

In reply to Mr. Smith, it is not practicable to take polar diagrams after nightfall at great distances unless the field at each point is taken as a mean over several days. It may be said that a polar diagram taken in such a way is not of great value if taken at a distance where fading is an important factor. Selective fading has been a pronounced phenomenon—in fact fading of a type which is unselective is relatively harmless when a set with good automatic volume control is being used.

The provision of separate machines for heating the filaments of the CAT14 valves actually effects an economy owing to the heavy nature of the switchgear on the generator side which otherwise is necessary. Also the percentage of spare plant can be reduced by this means. However, what is probably more important is that the method adopted at this station gives a simple method of individual adjustment of filament-heating current, which is of outstanding importance in connection with transmitter performance and valve life.

It is not understood why the 12 000-volt machines are objected to or why it should be desirable to use four machines instead of two, having regard to the cost of the necessary additional switchgear. We do not agree that insulating the machine from earth is a better method than insulating the core from the shaft. Our experience with a number of machines of the latter type had been satisfactory in every way.

We prefer " zero volume " to " reference volume," because the quantity is directly related to zero voltage-level. Further, " reference volume " has a variety of meanings in different countries. The time-constant of the programme meter is 200 millisec.

The centre pair of coils between the earth and the mast structure is inserted to provide a static leak between the mast and earth.

The " make-up " of distilled water in the circulating system is extremely small and dependent mainly on any small leak that may exist in pump glands or valve water-jackets. Owing to the low operating temperature of 120° F. the loss due to evaporation in the totally enclosed system is extremely small.

The answer to Mr. Field's question with regard to induction regulators is " yes." It is usual to employ one stage of doubling in master-oscillator circuits to obtain greater stability.

The size of the earth wire is determined largely by mechanical considerations. The arrangement described has been used at all the B.B.C. Regional stations and it has been found efficient, judging by the measurements at previous stations. No difficulty has been experienced due to corrosion of the earth wires.

The filament used in the CAT14 valve takes the form of a squirrel cage composed of tungsten wire. So far as we are aware, no indirectly heated cathode valve of this type with these characteristics is yet made commercially, although such a valve has been tried in Germany.

Regarding mast aerials, it is not practicable to construct a mast to act as a half-wave oscillator for a wavelength of 1 500 metres.

In reply to Capt. Gaskins, no regular tests of aerial insulation are made, but the aerial is periodically overhauled. No special treatment has been given to the masts at any of our stations beyond painting with one coat of red oxide at works and two coats of graphite or similar paint after erection. Repainting is usually done about every two years.

Mr. McDonald's question on anti-fading aerials has already been answered. No corrosion due to the distilled water in the copper pipework has so far been observed, although in some cases the copper is capable of imparting to the water an impurity which results in a slight deposit of copper hydroxide on the valve anodes.

We agree that there is a good deal of difficulty in lining-up the various methods of measuring and calculating effective height. An indication of the methods used and the difficulties experienced is given in the paper, and it is hardly practicable in this reply to deal with this subject at greater length.

We agree with Prof. Howe that the higher harmonic superimposed on the alternator wave-form shown on the oscillogram in Fig. 6 is due to a fault in the oscillograph. We also agree that it is possible to calculate the equivalent inductance and capacitance of the aerial from Fig. 25. This has in fact been done, and the results have been used for design purposes.

We are obliged to Prof. Howe for pointing out a misprint in Fig. 27; as he rightly points out, the condensers designated $2C_{21}$, $2C_{22}$, $2C_{25}$, should read $\frac{1}{2}C_{21}$, $\frac{1}{2}C_{22}$, and $\frac{1}{2}C_{25}$. The necessary correction has been made for the *Journal*.

In reply to Mr. Greig, it is not easy to say definitely whether four CAT14 valves have given better tuning results than a larger number of CAT6 valves, because the latter have never been tried, but it is practically certain that this would be the case. However, so far as adjustments are concerned, it is easier to adjust correctly the four CAT14 valves at Droitwich than the 14 CAT6 valves used by other stations. So far there have been no "rocky point" flash arcs at Droitwich.

In reply to Mr. Cooper, there are no protective devices used in connection with the filament-heating generators other than the overload trips on the motor switchgear. It would be difficult to damage a low-voltage high-current generator of this type by accidental short-circuit of short duration. Under the conditions of working, a sustained overload is, of course, impossible.